
Floating Silt Barriers for Ontario

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Foreword

The following report was prepared by Mr. Rick McLuckie as a partial fulfillment of course work at the Department of Civil Engineering at Queen's University at Kingston, Ontario. The report was based on information supplied by the Environmental Unit, Planning and Design Section, Northern Region, Ministry of Transportation and Communications.

Bruce Roberts
Senior Environmental Planner, MTC.

Abstract

The Ontario Ministry of Transportation and Communications (MTC) has recently employed a unique marine protection system to isolate construction-caused sediment in the immediate work site. Silt barriers were developed to minimize sediment contamination of sensitive downstream sites. A silt barrier is a vertical plastic curtain suspended on floats and secured to the bottom to form a giant settlement basin around the construction site.

Although silt barriers have been used in Ontario since 1972, they have not yet found widespread acceptance throughout the Province. The type of silt barrier used by MTC (a flexible curtain) works well, being 95% effective. They are relatively inexpensive, easy to place and durable. Success with the initial application of flexible silt barriers, with only minor problems, has warranted further use on other projects. This report outlines the MTC application of silt barriers, with consideration of other current practices.

Acknowledgements

Because the application of silt barriers is only ten years old, there is not a vast amount of material readily available. I would like to thank the professors, practicing engineers, government personnel, and trades people who provided me with numerous avenues of research.

I would like to express my gratitude to the Ministry of Transportation and Communications for access to files and resource material. I wish to acknowledge the special help given by Bruce Roberts, Senior Environmental Planner, MTC, Northern Region, in introducing the topic to me and providing invaluable information.

Lastly, I would like to thank my wife Suzanne, for her co-operation, devotion and patience.

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1/ Introduction

Sediment from soil erosion is the largest pollutant of our surface waters [15,18]. Although the movement of sediment is a natural part of the hydrological system, heavy construction is often considered one of the major sources of sediment [6, 10, 13, 16, 17, 24, 26, 27, 32]. The various phases of construction (i.e., clearing and grubbing, earth-moving, the excavation, borrowing, stockpiling or disposal of material, etc.) contribute to an accelerated rate of erosion compared with natural geologic erosion.

Increased public awareness regarding degradation of the environment has made officials more concerned about the detrimental effects of pollutants such as sediment (Appendix 1). This concern has resulted in a variety of erosion control techniques. Most of these controls involve either energy dissipation (to reduce the load-carrying capacity of run-off) or stabilizers (such as chemicals, herbaceous cover or artificial cover) to reduce erosion. Often, these controls do not prevent the transport of silt and clay fines [22]. Some require time to become established before they are effective. For others, their large initial cost is prohibitive. Also, most of these techniques are not applicable to dredging or fill operations which extend out into water bodies.

In 1972, the Ontario Ministry of the Environment authorized Ontario Hydro to try an experimental method of disposal of excavation material from the cooling water intake for the Lennox Generating Station [26]. A rectangular enclosure, 183 m x 91 m, was made of plastic curtain suspended by large floats fastened at intervals and anchored by massive concrete blocks (Appendix 2). Excavation material, dumped from barges, was retained inside the enclosure.

The curtain was designed as a "fixed" barrier. The large floats and anchors did not allow the barrier a high degree of flexibility or mobility.

In 1978, the Ontario Ministry of Transportation and Communications introduced flexible silt barriers at Vernon Lake Narrows. These silt barriers were patterned after similar barriers used in Florida, where they have been effectively employed to confine sediments from dredging [1, 2, 3] and sediments that had passed through conventional sediment controls [22]. The curtains were made of woven polyolefin material which was relatively inexpensive, light, and easy to place. At present, they appear to be a cost-effective, efficient method of confining sediment pollution. The purpose of this report is to describe the design, fabrication, placement, performance, and warrants of the silt barriers at Vernon Lake Narrows with respect to other barriers currently in use.

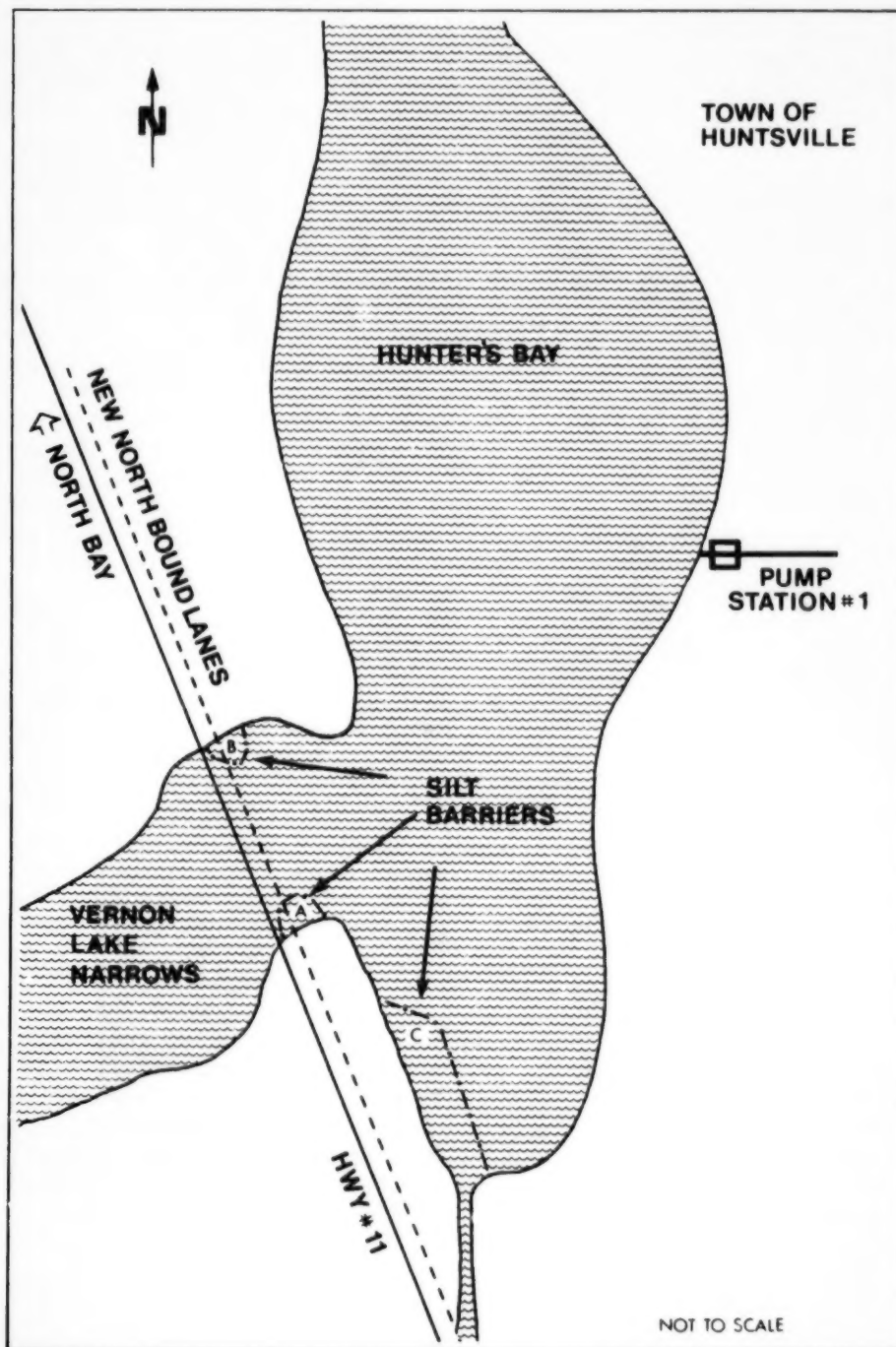


Figure 1/ Site Sketch of the Vernon Lake Narrows/Hunter's Bay Silt Barriers

3.3.1/ The Bottom-Anchored Flexible Silt Barrier

In water of depths up to 9.5 m the silt curtain can be anchored to the bottom and held at the surface by floats. This type of barrier was used at Vernon Lake Narrows/ Hunter's Bay.

3.3.2/ Materials

The floating silt barrier has three material components: the floats, the weights (anchors), and the barrier material.

3.3.2.1/ Flotation

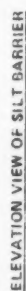
For the Vernon Lake Narrows curtain, 130 mm diameter ethafoam floats, 380 mm long, were attached to 10 mm nylon rope (Figure 2). The nylon rope was threaded through grommets in the top of the fabric. The grommets were spaced at 2 m intervals with a float centered between each pair of grommets (Figures 3 and 4). A small sinking problem occurred at sites A and B (Figure 1) due to inadequate flotation. This led to larger flotation and closer spacing being specified for the Hunter's Bay silt barrier.

Alternate fastening arrangements have been used. Instead of passing through grommets, the nylon rope (and sometimes the floats) pass through a heat-sealed or sewn sleeve at the top of the barrier. In Florida, the sleeve is filled with ethafoam, polystyrene, or other flotation material and sealed. A steel cable passes through the sleeve and connects the panels (Figure 5) [1, 22].

Sources indicate that, in some instances, "contractors have used old oil drums, etc., for flotation devices" [8]. The logic of replacing one form of pollution with another might be questioned.

3.3.2.2/ Ballast and Anchors

Weights are fastened to the bottom of the fabric to keep it in contact with the lakebed. The Vernon Lake Narrows/Hunter's Bay curtains employed concrete weights spaced on 2 m centres. The weights were made by filling a 1 L can with concrete and casting a wire loop in place [7]. The wire loop was used to attach the weights to grommets which ran along the bottom of the barrier (Figure 4). The intermittent weights were used because pre-construction investigations by underwater divers revealed a bottom littered with saw-logs, old stumps, and debris. It was felt that the intermittent weights would find their way to the bottom, giving better bottom conformity than alternative anchoring methods [23].



The "Florida" type barrier and the one used at Vermilion River have 8 mm galvanized steel chain running through a sleeve in the bottom of the barrier. The chain ballast allows the barrier to conform better to a regular bottom.

Also, the barrier must be anchored in position around the construction site (Figure 6). At each end of the barrier, the nylon rope joining the floats was secured to a 203 mm diameter timber post on shore. Anchors, made of 4.5 L cans filled with concrete, were placed inside and outside the barrier to maintain its shape and location. The concrete anchors were attached by nylon rope to the top of the barrier.

The "Florida" barrier and the one at Vermilion River employ commercial anchors to prevent the displacement of the barriers by winds and currents. Anchor lines are attached first to large buoys and then to the barrier. This way, the barrier will not sag or be pulled under the water by extreme currents [2, 22]. Bottom conditions determine the best type of anchor [2]. Danforth-type anchors should be used in sandy bottoms, whereas kedge-type or mushroom anchors should be used in mud bottoms.

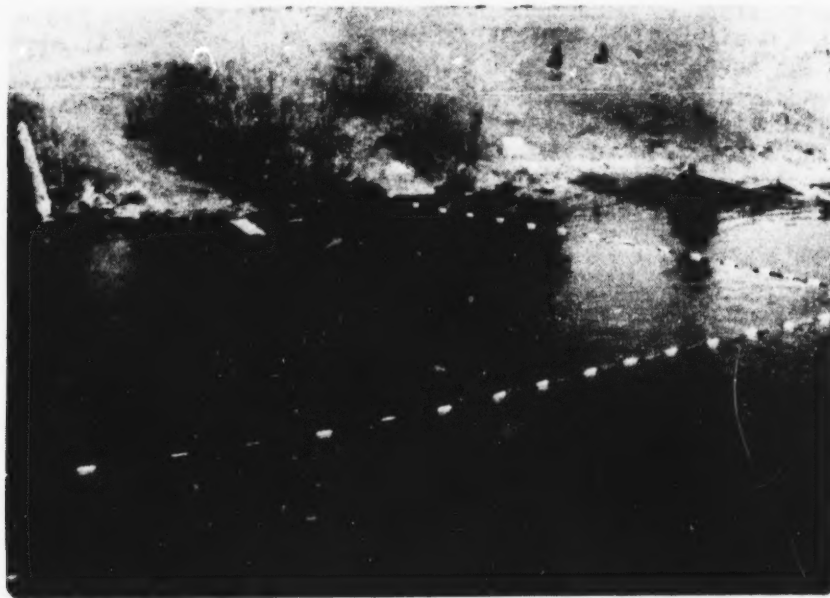


Figure 6/ A Positioned Silt Barrier Around Excavation Site
for North Abutment

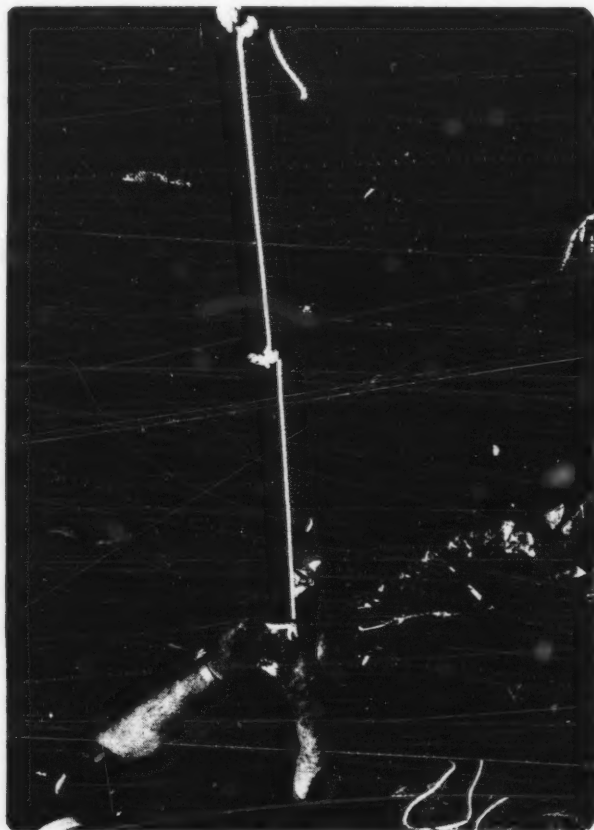


Figure 7/ Lacing Panels of Fabrene Together



Figure 8/ Barrier Placement of Vernon Lake Narrows

been in place and effectively containing sediment, a number of extra costs would have been incurred.

Silt curtain effectiveness is defined as the degree of turbidity reduction outside the curtain relative to the turbidity levels inside [30]. Readings were taken inside the barrier (during early December) where the draglines were working [23]. These readings were plus 200 N.T.U. at all times and three samples taken for testing were in the range of 240 N.T.U. Readings of 200 + were consistent inside the barrier while readings outside the barrier were about 2 N.T.U., as per Table 1. Pre-construction tests revealed background levels in the Hunter's Bay/Vernon Lake Narrows area of about 1 N.T.U., or less. Thus, the barrier effectiveness may be estimated at 97%, based on turbidity readings (Appendix 3).

The effectiveness of the barriers is strikingly pointed out in Figures 10, 11 and 12. The sediment-laden water was confined to the construction site. Careful examination reveals some sediment escaping under the barrier. It is difficult to obtain a tight bottom seal on an irregular lakebed. However, these photographs show very clearly the high degree of confinement that can be achieved.

There are numerous instances where the effectiveness of silt barriers has been documented [1, 4, 8, 14, 22]. Rivers and Allen [22] provide a detailed analysis of the performance of "Florida" type barriers. The two barriers they examined had turbidity reductions as high as 93% with average reductions of 72% and 68%. Other sources [14] indicate effectiveness of present barriers at about 85% to 90%. The barriers used by MTC at Vernon Lake Narrows/Hunter's Bay compare favourably. It should be noted that the Rivers and Allen study was for barriers across broad open reaches with water sources inside, which are more difficult situations to contain than a sheltered bay, such as Hunter's Bay.

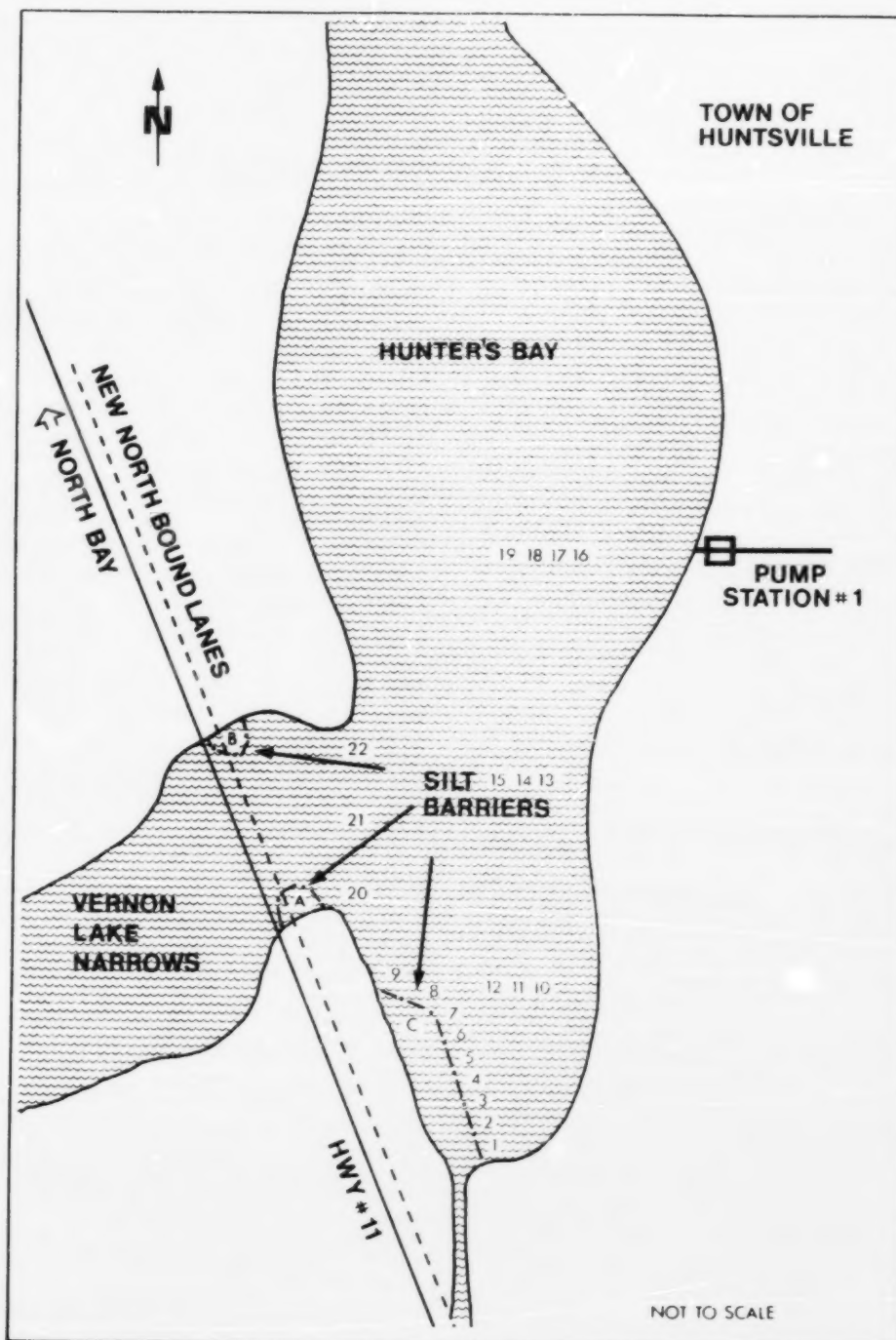


Figure 9/ Location for Turbidity Tests (1979-12-01)

Table 1/ Turbidity Tests Taken in Hunter's Bay 1979 12 01

Location Number	Description	Result (N.T.U.)*
1	Outside Silt Barrier	1.3
2	Outside Silt Barrier	1.0
3	Outside Silt Barrier	1.3
4	Outside Silt Barrier (Opposite Dragline)	2.5
5	Outside Silt Barrier	1.5
6	Outside Silt Barrier (Opposite Dragline)	4.3
7	Outside Silt Barrier	2.3
8	Outside Silt Barrier	1.0
9	Outside Silt Barrier	1.2
10	150 Feet From Shore	0.9
11	250 Feet From Shore	1.1
12	350 Feet From Shore	1.3
13	100 Feet From Shore	0.8
14	200 Feet From Shore	1.6
15	300 Feet From Shore	4.7
16	300 Feet From Shore	6.0
17	400 Feet From Shore	11.5
18	500 Feet From Shore (approx. location of intake)	19.0
19	600 Feet From Shore	10.0
20	In Channel From Bridge	4.9
21	In Channel From Bridge	2.0
22	In Channel From Bridge	2.6
Ambient Background (Pre-construction) Levels		0-1
Inside Silt Barrier with Draglines Working		200+

* N.T.U. = Nephelometric Turbidity Unit, formerly Jackson Turbidity Unit
(J.T.U.)



Figure 10/ Isolation of Sediment During Excavation for South Abutment

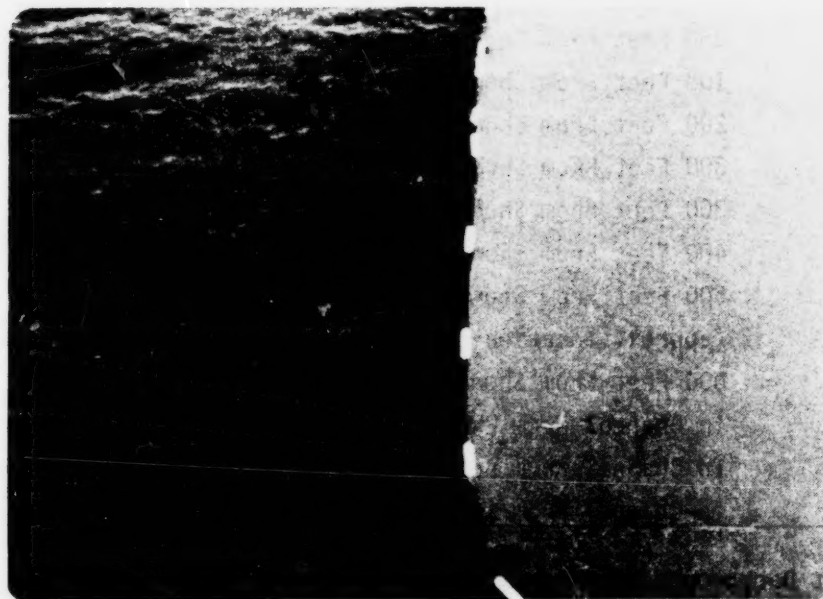


Figure 11/ Silt Barrier Effectively Containing Most of the Sediment

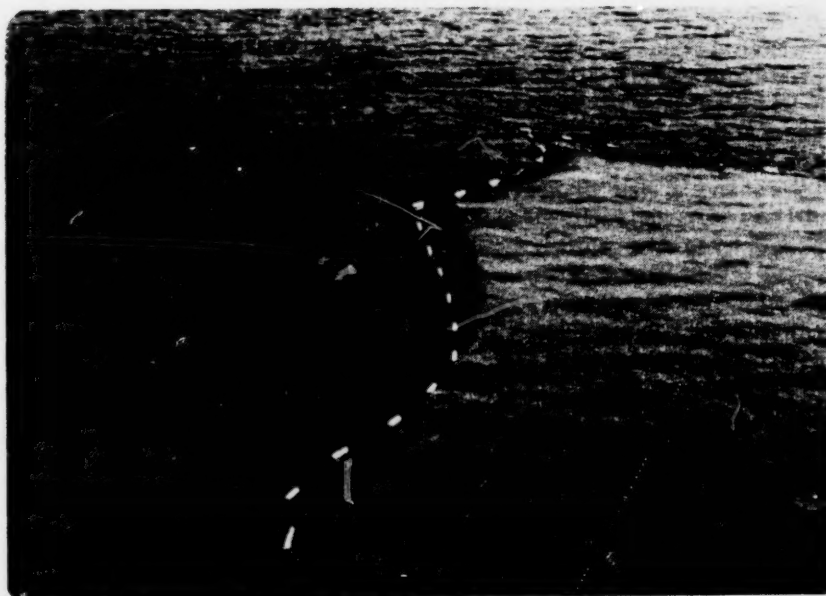


Figure 12/ A Silt Barrier Performing with Wave and Current Action

4.2/ Problems

The initial application of flexible silt barriers in Ontario was at Vernon Lake Narrows/Hunter's Bay. Usually, there are a number of problems associated with implementing a new procedure. These problems were minimized by thoroughly researching the application of silt barriers and through cooperation between MTC and Florida Department of Transportation personnel, the original designers of silt barriers [3].

There were two major difficulties encountered with the barriers. As previously described (Figures 10, 11, 12), some sediment escaped under the barrier where it did not conform to the bottom. Hunter's Bay had been the site of an old sawmill. The lakebed was littered with sawlogs [20]. The barrier had a number of gaps where it traversed these logs. The periodic anchor system was used to allow the anchors to go between the logs and stumps to give a better seal. Even so, there was not a perfect seal.

The second difficulty concerned the barrier being pulled under the water. This was apparent after the winter when there were sections of the barrier submerged. In a few places, increased stresses from the buoyancy of the floats had caused the grommets to tear out of the fabric. The reason for sinking has been postulated [2, 20] to be a result of the build-up of sediment along the bottom of the barrier.

Large pleats may develop at the bottom of a barrier in areas where the water level has been lowered or in the shallows of a constant depth barrier. In this area, the water levels in winter are lowered to allow storage for the spring freshet. As settlement of sediment begins, these pleats become covered. The weight of silt on the bottom begins to pull the barrier

under. Over time, much silt can build up on the barrier. Rips in the fabric make salvage less attractive. Provided that the whole barrier does not rip out, it will still retain large quantities of silt. To make the barrier less prone to having grommets ripped out, the Vermilion River curtain had the floats enclosed in a sleeve. The sleeve provided more resistance to tearing.

There were other reasons the barriers did not, perhaps, perform as well as expected [23]. Given that the barriers were containing underwater excavation sediments and that the contractor was having problems establishing adequate filtration mechanisms for the material from inside the caisson tubes for the piers, the north and south abutment barriers were used as settlement basins for this material. There were seven piers with six caissons per pier. Each caisson tube had about 35 m³ of material to be removed. This resulted in a large quantity of extra material, typically 670 m³ for each barrier, which was pumped onto the shore and allowed to filter down into the enclosure. This material in the small barrier enclosure tended to form a delta. The foreslope of this delta buried the barrier bottom and pulled the curtain under the water.

The nature of the work inside the long barrier at Hunter's Bay was expected to create a "mud wave" that may have pulled parts of the barrier under. The bottom, enclosed in the Hunter's Bay barrier, was to be excavated and back-filled with granular material.

This method was expected to result in a mud wave pushing out from the fill through the soft subsurface material. This process may have resulted in sawlogs, stumps, and material being pushed up and covering the pleats of the curtain.

5/ Silt Barrier Design

Very few silt barrier applications are the same. Each barrier must be designed for a unique site-specific set of conditions. There are two aspects the designer must consider. First, there should be sufficient warrants to justify the placement of a curtain. Then, once a curtain has been deemed necessary, a detailed design is required.

to lower the barrier when a boat or barge needs to pass. Weights sufficient to sink the barrier would be put over it. After the barge had passed, the weights would be pulled up and the barrier allowed to float back to the surface. The barriers at Vernon Lake Narrows posed no problem to small watercraft. To cross the barrier, the driver would raise the outboard motor permitting the boat to float over the top (Figure 14).

5.1/ Warrants

The main reason silt barriers were developed was to prevent significant environmental impacts [3, 22]. They have been employed to prevent impairment to domestic water supplies [8, 19], recreational lakes [22], and sensitive ecosystems [19]. In other areas, the barriers have been used to comply with pollution emission standards as set by environmental protection agencies [1]. Given that a sensitive site exists downstream from the construction area, a silt barrier can be beneficial in minimizing impacts.

For dredging operations or underwater excavations, there is no containment system that has the flexibility of silt curtains. There are extremely durable barriers with steel cable reinforcement. They are mobile enough to follow floating dredges but still are effective [1, 8].

In areas where marine traffic must pass through the construction site, fabric curtains should be used. Whereas sheet piling would pose a formidable barrier, silt curtains can be designed to allow traffic into or through the site. Gate sections can be designed into the barrier [8]. As can be seen in Figure 13, these floating "gates" do allow some sediment outside the construction area. The amount of sediment, however, is minimal. An alternative to gates is

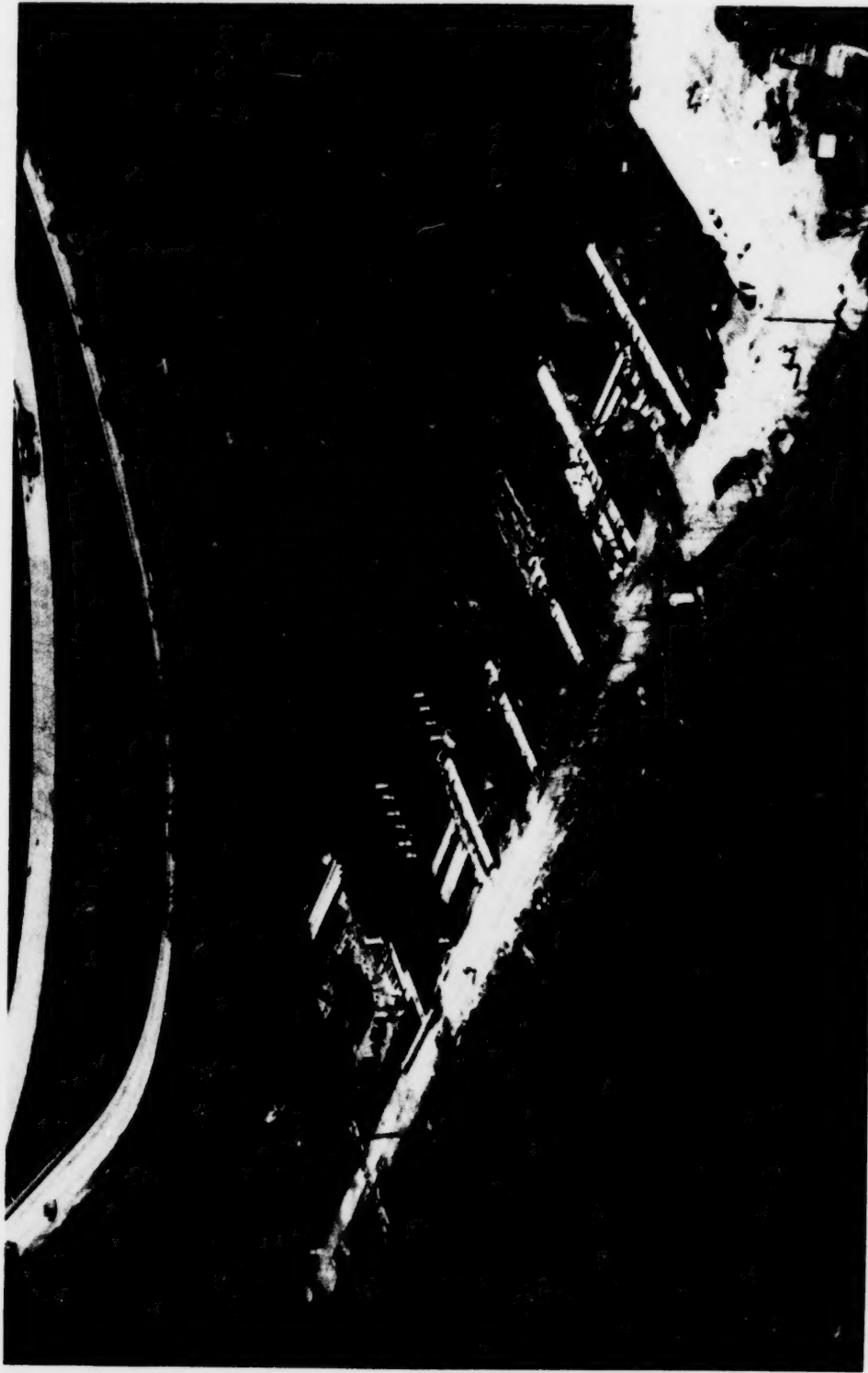


Figure 13/ Silt Curtains Used for Bridge Construction in Lake Whitehurst, Norfolk, Virginia
Note "gate" section allowing sediment out (U.S. Dept. of Transportation).

On large projects, silt barriers become cost-effective. The cost of the material for the barriers at Vernon Lake Narrows amounted to only one-sixth of one percent of the total cost of the project [7]. At present, prefabricated manufactured barriers can run as high as \$49 (Canadian) per linear metre (\$15 per linear foot) [1]. These barriers are extremely durable, with two steel cable loadlines (one of which runs below the waterline for increased stability) and have aluminum collars for connecting adjacent panels. Usually, these barriers may be salvaged.

The two barriers in Vernon Lake Narrows, one 89.7 m long and the other 109.8 m long and both 3 m deep, cost approximately \$6000 installed [20]. Material costs, including floats, anchors, attachments, fittings, etc., were about \$6/m². Installation and removal makes up a large portion of the costs. The cost of this type of barrier is approximately \$30 per linear metre for a 3 m deep barrier.

Unfortunately, the salvage value was minimal. Fastening areas deteriorated, and rips and tears also reduced the amount of fabric salvagable. The sediment on the bottom of the barrier made removal of the Vernon Lake Narrows curtain difficult. In Hunter's Bay, the barrier will be removed by a diver cutting along the bottom of the barrier. It is expected that leaving the bottom of the barrier will cause less disturbance than pulling it out.

The purpose of considering costs, with a discussion of warrants, is to emphasize that, although silt barriers are inexpensive, in light of the total costs of large projects, they are not economical for all projects. For small projects, disposable silt barriers may add more cost and provide little benefit in return. Environmental provisions are not readily acceptable if they make up a significant amount of the total contract price. For small projects, other measures such as time constraints, diversions, and earth cofferdams may be more cost-effective.

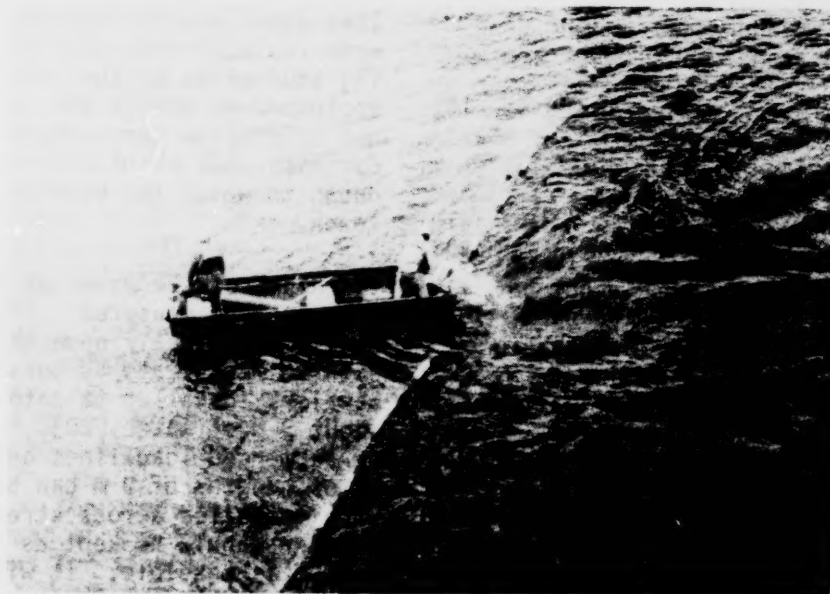


Figure 14/ Small Watercraft Crossing Barrier

5.2/ Design Considerations

After deciding upon a silt barrier system of sediment control, there are a number of things the designer must consider. When the barrier is to be used on an underwater excavation, the various hydraulic factors should be addressed. Sometimes it is necessary to supplement conventional erosion controls with a form of silt barrier (staked, floating, etc.). Normally, it is too expensive to use floating barriers to contain run-off erosion, especially when other techniques such as early sodding and seeding, straw bale check dams, sediment traps, and silt fences are readily available. However, for some sensitive sites, it is necessary to use silt barriers when conventional techniques do not adequately control erosion [22]. In such areas, a comprehensive erosion control scheme is necessary. A prediction as to the amount of sediment is required. A variety of models exist that attempt to provide this estimate [13, 17, 26, 27]. By establishing a design volume of sediment, the types and capacities of retention structures, the amounts of cover required, and any special provisions can be addressed in the detailed design stage.

5.2.1/ Duration of Construction

An important design consideration is the duration of construction (i.e., how long the barrier must be in place). Untreated fabrics experience rapid deterioration and should not be used in silt barriers [3]. The duration of installation has a direct relation to the amount of sediment contained. Silt on the barrier bottom makes removal of the barrier difficult. Over long periods of time and in areas where there is no reversing current that would "clean" the silt from pleats, barriers intended for salvage would require a regular maintenance program. The maintenance program would involve raising the

barrier so that the silt in any pleats would be removed. For barriers left in place over the winter, divers would be required for this under-ice maintenance.

5.2.2/ Hydraulic Conditions

The hydraulic conditions of the watercourse must also be considered in designing a silt barrier. The severity of the current determines the number of anchors required and the shape of enclosure. The barrier should be slanted, not perpendicular, to the direction of the current. This reduces pressure on the curtain. Slack in the length of the barrier makes installation easier and reduces stress from wave action during high winds [2]. Should the crossing of a current be unavoidable, it may be necessary to investigate the use of steel cable load lines below the water level. These load lines, when threaded through grommets part way down the barrier, give it added strength and stability. Load lines can also be used in barriers that are required for deep water installations. The steel load lines may be supplemented or even replaced with spud piles. Placing spud piles in the corners of the enclosure or across the current would not only allow the curtain to resist currents, but would also increase the depth to which the barrier could reach.

The depth of the water at the proposed site must be measured. The barrier should rest freely upon the bottom with as few pleats as possible. Most barriers installed to date are in about 3 m of water [20]. With the use of submerged load-lines and/or spud piles, depths of 9 m can be reached. When installed across streams, the barrier should be kept as near the bottom as possible. It will not remain on the bottom because the current must escape beneath it [2].

The bottom of the watercourse can affect design. A bottom littered with debris may require periodic anchors. A chain ballast is suited to a smooth bottom. The type of anchors required depends on the bottom soil type.

5.2.3/ Placement Methods

The placement of barriers has a number of design considerations. The proposed method of placement should minimize effort, time, and the possibility of damage to the barrier. The suggested method of placement will vary depending on the location.

For containment in a lake or bay, placement should be made by first fastening the barrier to a post on shore. Then the furled barrier is pulled, by boat, to form an enclosure around the site. The free end is attached to another shore anchor point. Anchors are placed at various locations to give the desired shape. Lastly, the furling ties are cut and the ballast then pulls the barrier down into position.

For river applications, similar techniques are used. When protecting a small area on the side of a river, the same method used in lake or bay sites is employed. The initial anchor point should be on the upstream side of the construction site. In this way, the current will help carry the barrier downstream. Once tied-off downstream, anchors can be positioned forming a half-moon configuration.

When the barrier must completely cross the river, it is anchored on one shore. If possible, it is then stretched full length along the upstream bank. A boat then takes the upstream end and crosses the river. The anchor point on the opposite shore should be downstream of the initial anchor (this allows for slant). The barrier will drift downstream in the current. Manufacturers [2] claim that

for lengths less than 90 m, anchors mid-stream are not needed. Any anchors placed in this situation should be accompanied by buoys to stop the current from pulling the barrier under.

In all cases of placement, the furling ties should not be cut prior to positioning the barrier. With the barrier down, water pressure makes movement difficult. Also, an unfurled barrier is extremely susceptible to the wind. Under windy conditions, a silt barrier makes a perfect airfoil, as seen in Figure 15. This airfoil tendency makes placement very difficult and may damage the material.

5.2.4/ Materials

As discussed previously, there are two types of plastic material available: either a woven permeable, or a coated impermeable, polymer fabric. Both have been used in silt barrier applications. Discussion with certain authorities revealed that woven permeable fabrics, when used across a current, may have clogged with fines. Clogging has been noted to reduce permeability when filter fabrics were used in soil filter systems [5]. However, documentation of this process in open water was not found. Should this clogging occur, there would be little difference between an impermeable fabric and a clogged woven material. A decision as to what material to use should be based on cost, durability with exposure to water and ultraviolet light, strength, weight, and response to freeze/thaw action.

5.2.5/ Other Considerations

A check should be made to see if there are any aquatic plants or algae, marine animals, or chemicals that may attack or hinder the barrier. An environmental assessment, which is required in many jurisdictions, would likely include such information.

Perhaps some consideration should be given to the establishment of an aquatic environment behind the barrier prior to removal. This aquatic "seeding and mulching" may prevent future scouring.

If the barrier is to be salvaged, then an easy method for retrieval has been found [2]. A light skiff is put underneath the barrier at one end. Two men pull the barrier up and furl it as they slide the boat along until they reach the other end. The anchors are drawn up and the barrier towed in, where it is immediately cleaned, dried, and then stored. For the non-salvageable barriers, cutting any sections under sediment would minimize disturbance. Even for these barriers, anchors, floats, rope, ballast, and some small sections can be reused.

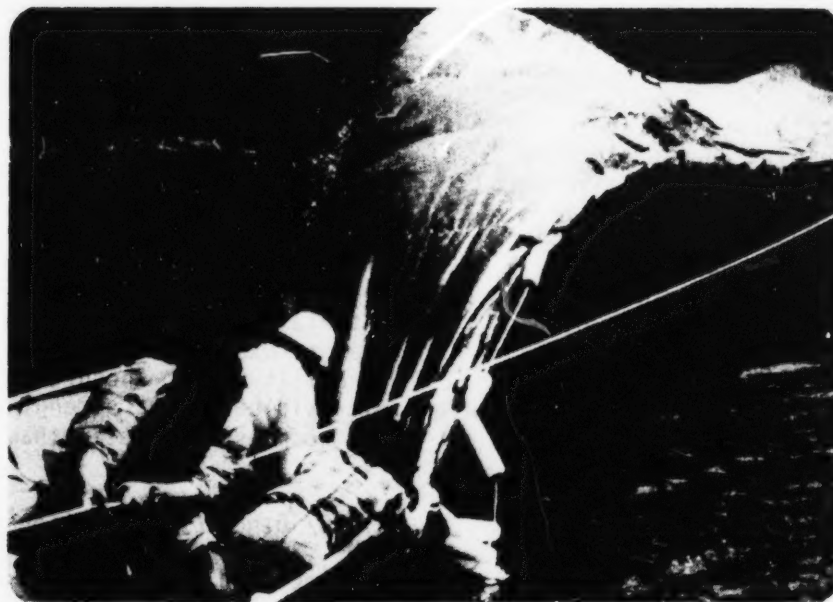


Figure 15/ "Air Foil" Problem with Silt Barriers

6/ Conclusions

Silt barriers add a new dimension to preventing detrimental sediment impacts to the environment. When underwater excavation is required, silt barriers can be used with significant reductions in sediment load. Occasionally, silt barriers are needed to supplement conventional erosion control practices. The high cost of silt barriers, with respect to other erosion control devices, makes silt barriers practical only for large projects and/or projects with very environmentally sensitive sites.

There are two current designs of silt curtains. The "Florida" design is based on salvaging the entire barrier. Naturally, it costs more for an extremely durable barrier but it is possible to lease barriers for short-duration projects [1]. The Ontario Ministry of Transportation and Communications opted for a less expensive barrier having only some parts reusable. In light of the problem with silt build-up on the bottom of barriers which are left stationary for long periods, this seems to be an excellent plan. A regular "cleaning" or maintenance program would be required if barriers were to be reused. Under ice conditions, this would be expensive. Salvagable barriers may well be effective for short-duration projects that operate in ice-free conditions.

The disadvantage in using the unsalvagable barrier is that it becomes unattractive on small projects. The unsalvagable barrier, even after recycling reusable parts, adds extra costs to the project. These costs can be significant. A controversy seems inevitable between engineers/economists arguing that the cost of silt barriers is too high for small projects to provide protection against impacts which the environmentalist perceives.

Silt barriers have proven their worth at Vernon Lake Narrows. This inexpensive means of controlling sediment is flexible, easy to place, and of little inconvenience. For these reasons, silt barriers will be applied to more projects throughout the province.

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Appendix 1

Detrimental Impacts of Sedimentation

An increased sediment load in a watercourse can cause a variety of adverse effects. Not only can the natural environment be degraded but human concerns may also be affected.

A.1/ Maintenance on Hydraulic Structures

Sedimentation reduces the efficiency of channels, pipes, and culverts. Large sediment loads significantly shorten the service life of dams and reservoirs. Regular maintenance programs (dredging, etc.) are required on many hydraulic structures to maintain their holding or carrying capacities. Without such programs, flooding, excessive downstream velocities, lowered storage capacity, etc., may arise.

A.2/ Altering Natural Aquatic Habitats

Hess [16] examined the effects of road construction on aquatic insects. He found a decline in most of the aquatic insect populations of the South Fork of Casper Creek, where a logging road was built, when compared with the undisturbed North Fork of Casper Creek. The only insects which increased in numbers in the South Fork were those which normally thrive in polluted, highly-turbid conditions.

Cordone and Pennayer [11] found a dramatic decrease (75% to 85%) in the benthic communities, as far as 16 km downstream from a large sediment source, a gravel-washing plant. They also observed that there were fewer fish in the discharge area and those found there were in poorer condition.

Although Wallen [31] did not detect behavioural differences in warm water fish until turbidity levels of 20 g/L and lethal concentrations in excess of 100 g/L in aquarium studies, the

effects of sediment should not be neglected. Fish migrate from hostile environments [11]. In turbid conditions, "clean-living" fish have been replaced by carp, catfish, etc. [25-1]. Buck [25-15] found that the average total weight of fish produced in clear ponds (less than 0.025 g/L) was approximately 1.7 times greater than in ponds with intermediate turbidity (0.025-0.1 g/L) and approximately 5.5 times greater than in muddy ponds (greater than 0.10 g/L). Increased sediment decreases fish spawning areas, lowers embryo survival, and reduces the productivity of stream-bottom invertebrates [25-22, 6].

A.3/ Water Quality Requirements

The placement of suspended sediments within a water supply reservoir has a number of impacts [21]. There are increased treatment costs to remove suspended solids to comply with government regulations regarding potable effluents.

Water quality may also be degraded by other pollutants that are associated with the suspended load. Sediments reflect the parent soil material from which they come. Minerals, chemicals, and elements such as nitrogen and phosphorous or organic materials are all likely to be present in many eroded soils. Once released into the watercourse, they become additional pollutants.

Appendix 2

Ontario Hydro's "Fixed" Silt Barriers

In 1971, Ontario Hydro applied to the Canadian Department of Transport to dredge an intake system in Lake Ontario for the Lennox Generating Station [28]. This work involved the removal and disposal off-shore of 21 000 m³ of overburden and 18 000 m³ of rock. As part of the approval, the Ontario Department of the Environment stipulated that the overburden be disposed of on land or within a completely-dyked area along the shoreline.

Ontario Hydro considered that a suspended fabric curtain enclosure might be effective in containing turbidity caused by dumping silty material into the lake and, thus, alleviate the concerns of the Department of the Environment. Although model testing of such an installation under various current, wind, and dumping conditions was recommended, time did not permit it. Approval was given for a full-scale test of the curtain enclosure providing that, if performance was unsatisfactory, the original requirements would be implemented. This approval was subject to certain criteria as to the installation of the curtain enclosure and degree of turbidity permitted, and the type of equipment to be used.

The curtain enclosure was rectangular in shape, 180 m x 90 m, and was located in depths of water from 7.5 m to 12 m. The curtain extended from the surface to within 0 to 0.6 m from the lake bottom. The curtain was attached to 16 mm diameter plastic pipe via nylon rope through the grommets in the fabric. The plastic pipe was attached to Durafoam Styrospan floats, 2 m x 1.2 m x 0.5 m thick, placed 45 m apart along the length and 30 m apart along the width. The curtain was anchored at the corners by a group of three concrete anchor blocks, about 3.2 t each.

Two concrete anchor blocks of the same weight were placed below each float along the perimeter. The bottom of the curtain was held down by No. 11 (B.E.) reinforcing bars wired to the fabric. The nature of this barrier was such that it may be considered immovable or fixed.

The turbidity outside the barrier was not to exceed 10 Jackson Turbidity Units (J.T.U.); this was complied to. In general, readings outside the barrier were less than 6 J.T.U. and only exceeded the 10 J.T.U. limit on one known occasion. Inside the enclosure, there was between 0.3 m and 1.5 m (average of 0.9 m) of material dumped. The average current speed at the site was 0.06 m/s with a maximum of 0.18 m/s.

It was found that the concept of enclosing a disposal site with a curtain appeared to be successful. The location for this site was sheltered in the lee of Amherst Island and it was felt that this was significant in preventing the destruction of the curtain by wave action. A report [28] on the project recommended hydraulic modeling of future projects and elongated diamond or cigar shapes to minimize exposure to wind and waves.

Appendix 3

Analysis of the Effectiveness of the Vernon Lake Narrows/ Hunters Bay Silt Barriers

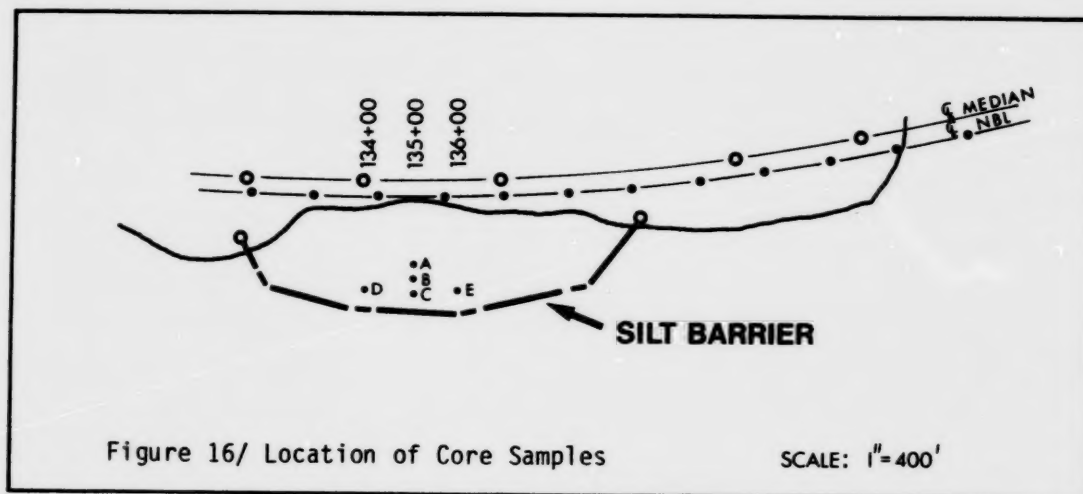
Samples were analysed for the amount of sediment in suspension. A sample taken in 1978 12 19, behind the barrier, at a turbidity of 240 N.T.U., had an average of 0.47 g/L of sediment in suspension (Table 2). Mixed samples at 200 N.T.U., made with material similar to that found at the site, yielded an average of 0.37 g/L.

On 1980 02 18, five core samples were taken through the ice behind the Hunter's Bay barrier. The purpose of

these samples was to determine the type, and estimate the quantity, of material behind the barrier. The locations of these samples are found on Figure 16. The profiles for the samples are given in Table 3. On these profiles, the approximate location of the old bottom is noted. Hydrometer tests (particle size distributions) were made on specimens taken at different levels of the core samples (Figures 17-27).

Table 2/ Sediment Concentrations for Samples

Samples	g/L
240 N.T.U. - 1978 12 19	.46
240 N.T.U. - 1978 12 19	.40
240 N.T.U. - 1978 12 19	.50
240 N.T.U. - 1978 12 19	.53
200 N.T.U. - Mixed	.28
200 N.T.U. - Mixed	.25
200 N.T.U. - Mixed	.47
200 N.T.U. - Mixed	.50



From the particle size distributions (P.S.D.), it is apparent that the silt barrier had contained a large quantity of clay and silt fines. P.S.D. samples 80-MBG-5 and 80-MBG-6 indicated a high amount of sand (Figures 17 and 18). The bore hole, from where these samples came, was the closest hole to the toe of fill. This high sand content probably came from either the erosion of the fill or the bore hole being in or near the toe of fill. The other P.S.D. samples taken above the old bottom showed very high clay-silt contents, from 90% to 98%.

The profiles of the bore holes indicate that the silt-clay deposit ranges from 0.15 m to 0.60 m. It appears that there is at least an average of 0.3 m of silt-clay deposits over the bottom of the enclosure. Estimating the area of the enclosure (Figure 16) at 15 800 m², yields 4700 m³ as the volume of sediment behind the barrier. Assuming a density for the sediment of 2500 kg/m³, then the mass of sediment behind the barrier would be 1.2 x 10⁷ kg. Authorities will generally agree that the waters with turbidities of 200 N.T.U. are polluted. For water samples with turbidities of 240 N.T.U. (definitely polluted), concentrations of sediment were about 0.5 g/L (Table

2). Therefore, if it is assumed that the mass of fine sediments had reached the watercourse and been uniformly dispersed, an estimate as to the quantity of water that might have been degraded can be made. For a concentration of 0.5 g/L, the 1.2 x 10⁷ kg could have polluted 2.4 x 10⁷ m³. Compared with Hunter's Bay, which has approximately a 3 m average depth and an area of 6.5 x 10⁵ m² (1:50 000 topography map), this would be about 12 times its size. Samples taken behind the barrier (240 N.T.U.) when draglines were working showed that even after two to three days of settlement, there were still fines in suspension. This would have provided adequate time for dispersion of the sediment-laden water.

Inside the barrier, turbidity levels were 200+ N.T.U. and reached levels as high as 240 N.T.U. (1978 12 19). Outside the barrier, levels were in the neighbourhood of 5 N.T.U. (Table 1). Ambient background levels were from 0 to 1 N.T.U. The effectiveness of the barriers, based on turbidity units, is 195/200, or about 97%.

TABLE 3/ Profiles of Core Samples

Sample	Depth	Field Textural Class	P.S.D. Sample
A			
Sta. 135+00 193' Rt. of Centreline	0 - 11.5'	Water	80-MBG- 5 (Fig. 17)
	12.5' - 13.5'	Fine-Medium Sand	80-MBG- 6 (Fig. 18)
	13.5' - 14.5'	Medium Sand	80-MBG- 7 (Fig. 19)
	15' - 16'	Silt (Soft)	80-MBG- 8 (Fig. 20)
	16' - 17'	Silt (Soft)	
	19' - 20'	OLD BOTTOM Silt (Stiff)	80-MBG- 9 (Fig. 21)
B			
Sta. 135+00 218' Rt. of Centreline	0 - 9.5'	Water	80-MBG- 3 (Fig. 22)
	9.5' - 10.5'	Silt with Fine Sand	80-MBG- 4 (Fig. 23)
	10.5' - 11.5'	Silt with Fine Sand	
	11.5' - 14'	OLD BOTTOM Muck (Amorphous)	
C			
Sta. 135+00 243' Rt. of Centreline	0 - 9.5'	Water	80-MBG- 1 (Fig. 24)
	11' - 12'	Silt (Top 4" Firm)	80-MBG- 2 (Fig. 25)
	12' - 14'	OLD BOTTOM Muck (Amorphous)	
D			
Sta. 134+00 243' Rt. of Centreline	0 - 10'	Water	80-MBG-10 (Fig. 26)
	10' - 10.5'	Silt	
	12.5' - 14'	OLD BOTTOM Muck (Amorphous)	
E			
Sta. 136+00 243' Rt. of Centreline	0 - 11.5'	Water	80-MBG-11 (Fig. 27)
	11.5' - 10.5'	Silt	
	12.5' - 14'	OLD BOTTOM Muck (Amorphous)	

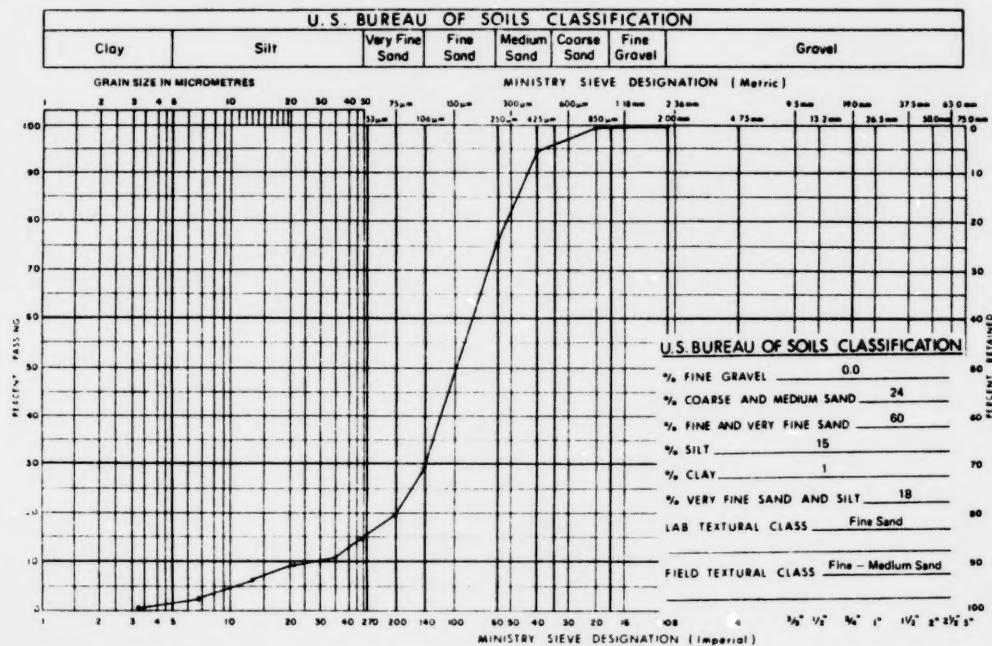


Figure 17/ Particle Size Distribution for 80 MBG-5

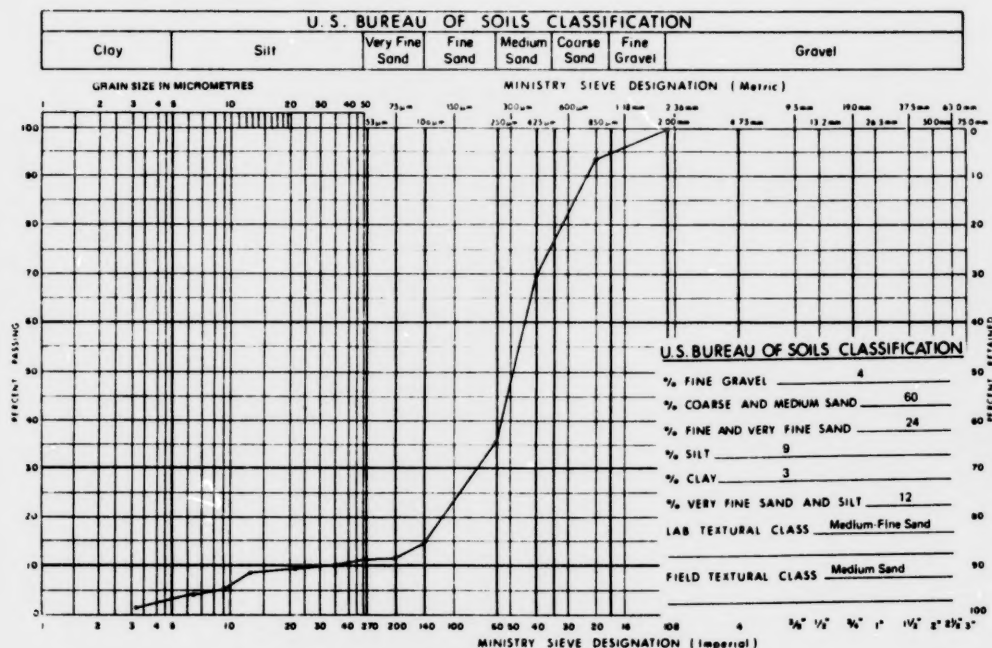


Figure 18/ Particle Size Distribution for 80-MBG-6

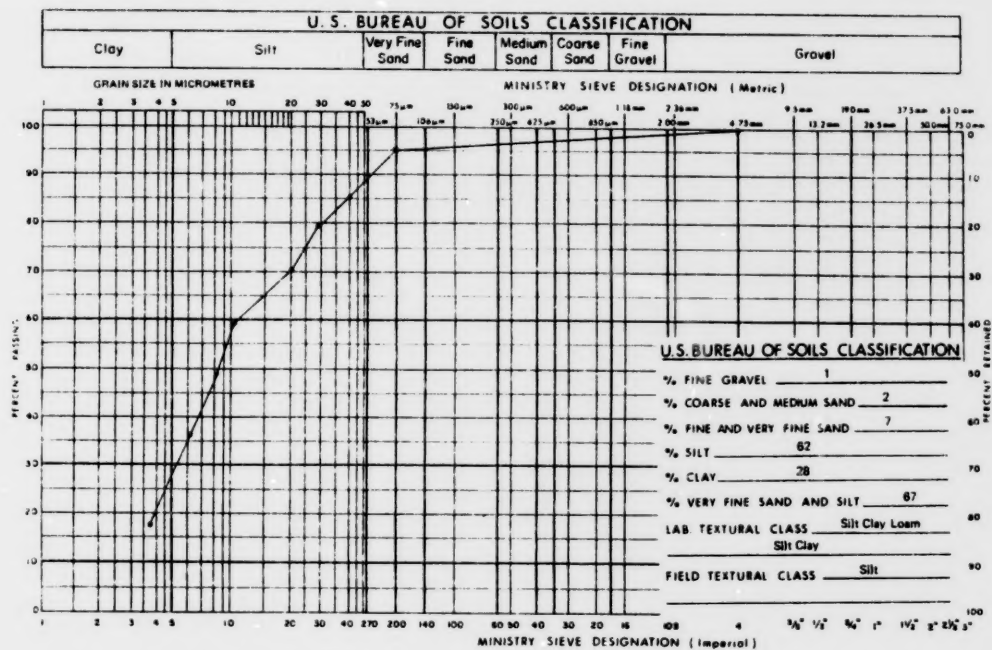


Figure 19/ Particle Size Distribution for 80-MBG-7

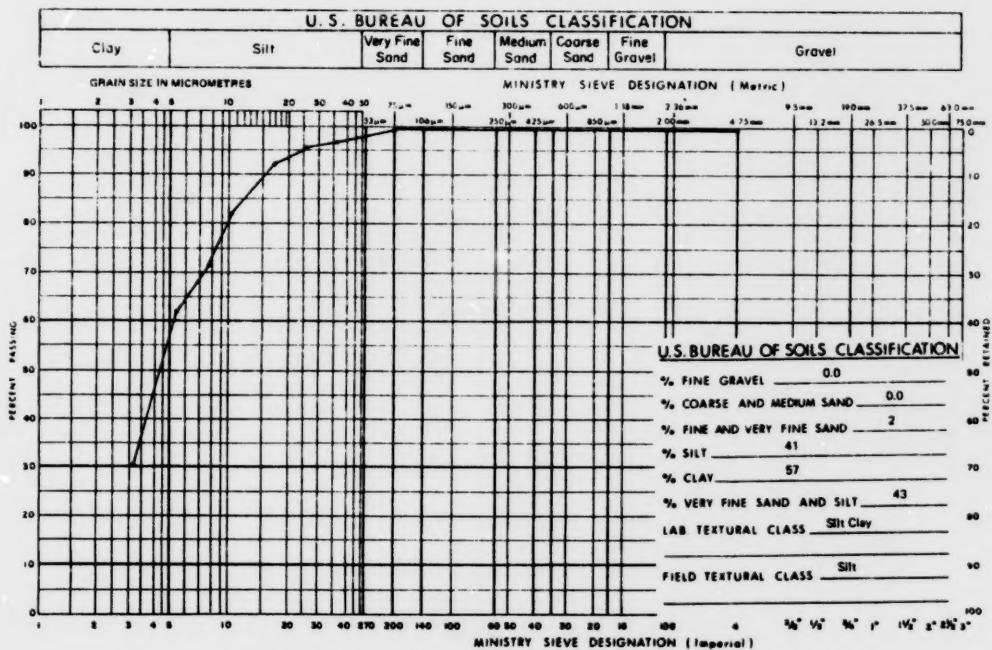


Figure 20/ Particle Size Distribution for 80-MBG-8

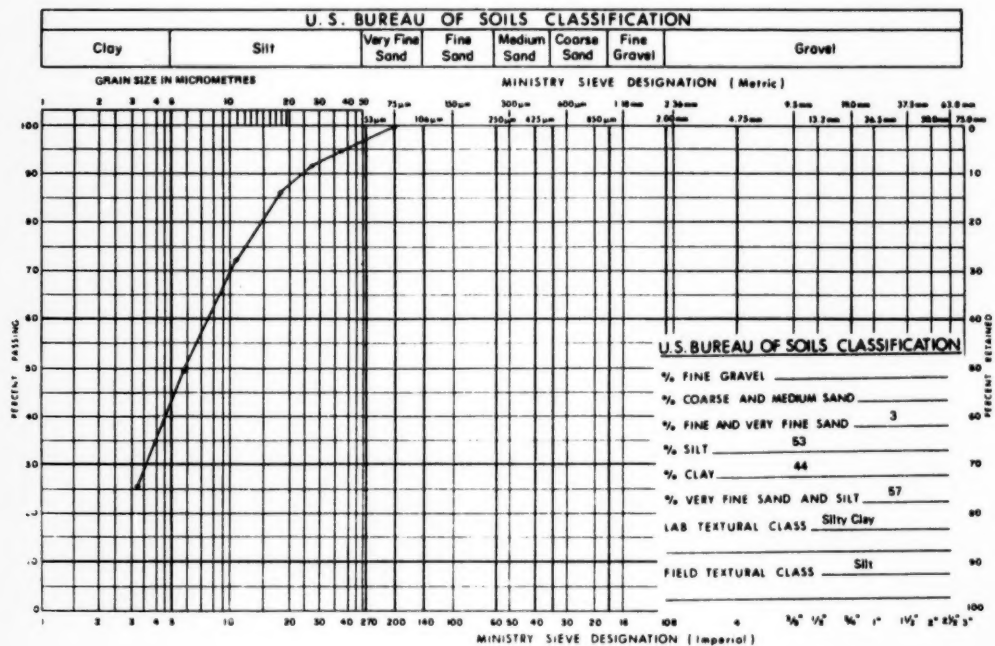


Figure 21 / Particle Size Distribution for 80-MBG-9

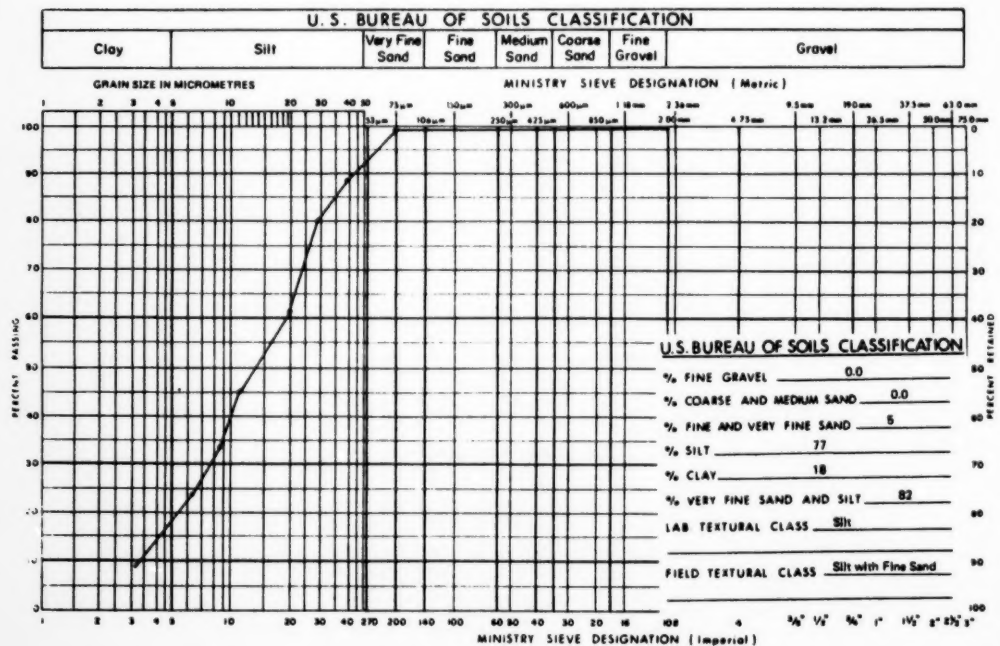


Figure 22/ Particle Size Distribution for 80-MBG-3

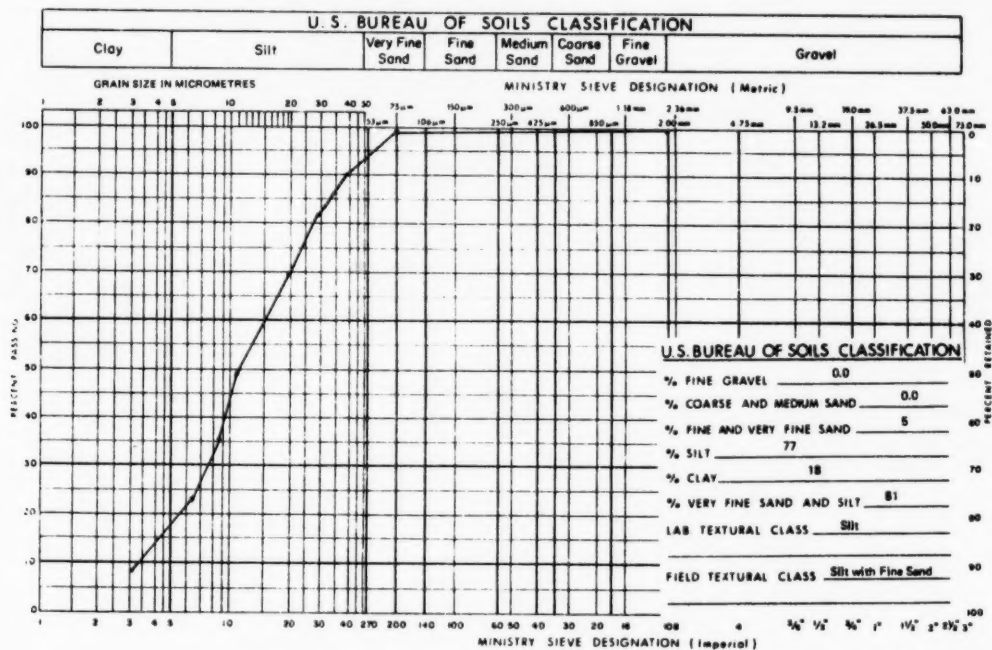


Figure 23/ Particle Size Distribution for 80-MBG-4

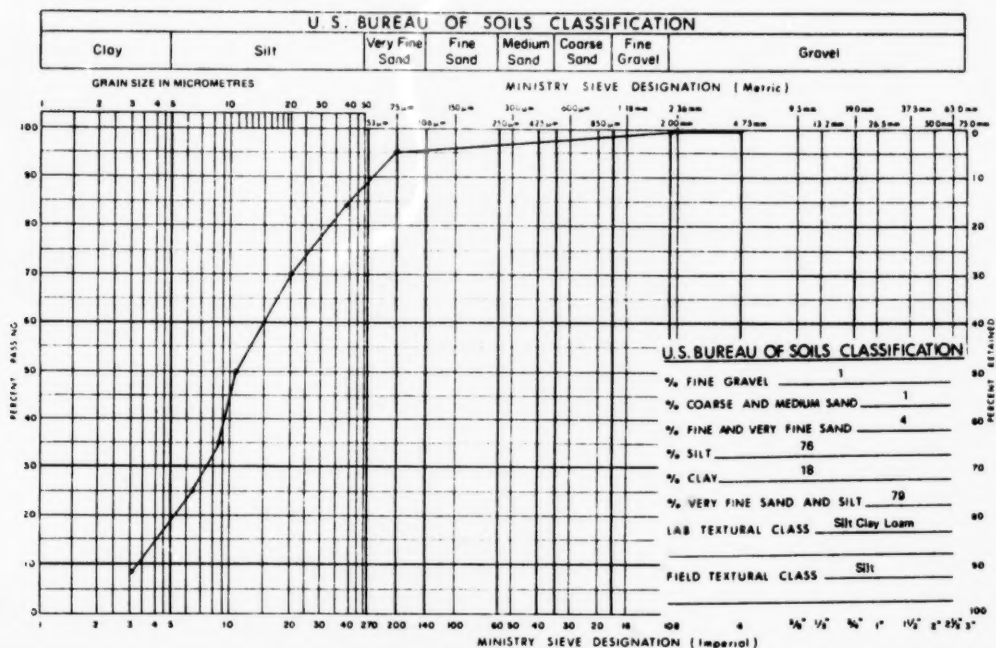


Figure 24/ Particle Size Distribution for 80-MBG-1

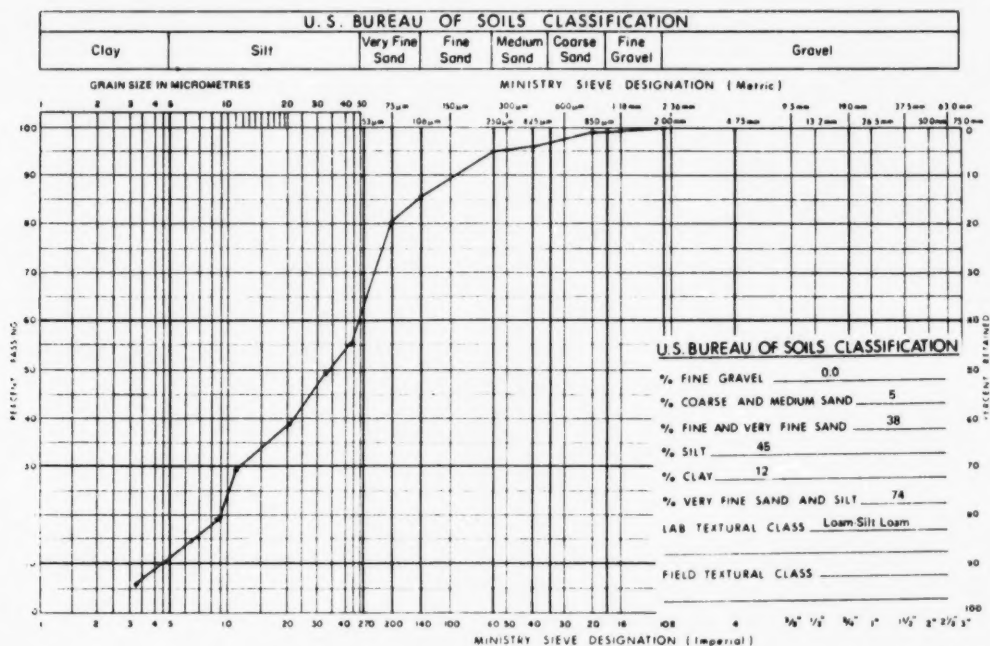


Figure 25/ Particle Size Distribution for 80-MBG-2

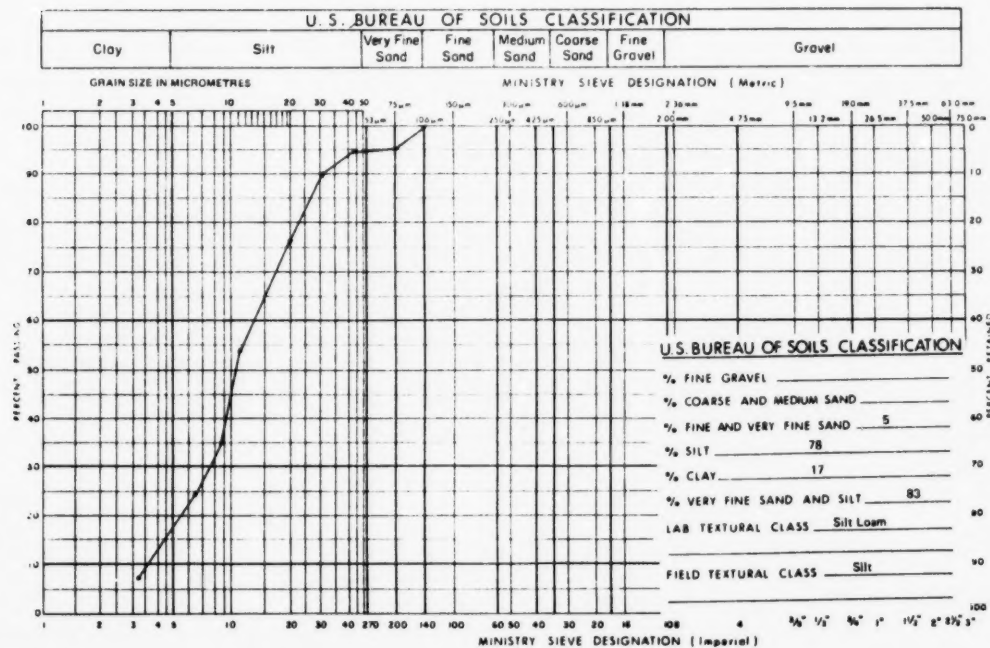


Figure 26/ Particle Size Distribution for 80-MBG-10

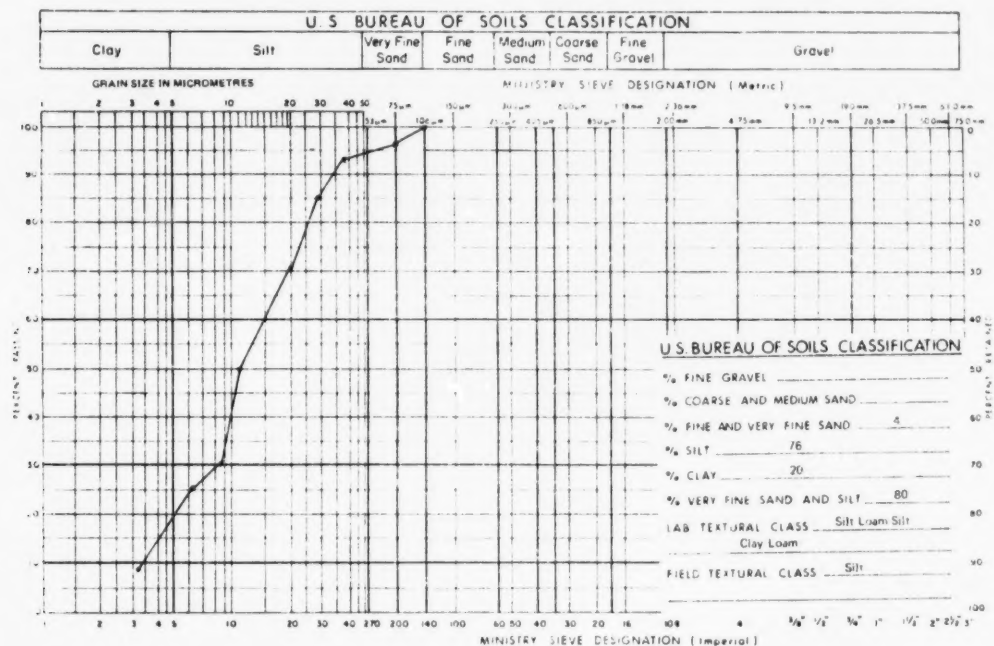


Figure 27/ Particle Size Distribution for 80-MBG-11